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The use of flexural forward modelling to predict the generation of accommodation space, Cooper-Eromanga Basin, South Australia

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This study details flexural backstripping and forward modelling of the development of the Cooper-Eromanga Basin on a viscoelastic lithosphere, in order to examine the contribution of load-induced subsidence to the generation of accommodation space. The flexural response to sedimentary load in the Cooper-Eromanga Basin has been analysed for various lithospheric parameters. Modelling has been used to determine the relative influence of load-induced basement level change vs tectono-eustatic processes, as contributors to accommodation space development.

Variations in the flexural parameters used in the model produce some change in the calculated values of load-induced and tectono-eustatic accommodation space generation. However, the contributions from the various processes retain similar orders of magnitude, regardless of flexural parameters.

In the early stages of the development of the Cooper Basin (186 to 158 Ma), there is significant load-induced amplification of tectonic subsidence (by up to 1.5 km for a lithospheric elastic thickness of 20 km), but accommodation space is predominantly due to tectonic processes.

In contrast, load-induced subsidence exceeds that due to tectonic processes during the later stages of basin development. Between 158 and 113 Ma, load-induced subsidence may be as much as 0.7 km, while the maximum tectonic subsidence is 0.5 km, for a lithosphere of 20 km elastic thickness. From 113 Ma to the present, again for a lithosphere of 20 km elastic thickness, the load-induced subsidence may be as much as 1.3 km, while the maximum tectonic subsidence is 0.8 km. The predominance of flexural-isostatic load compensation from 158 Ma to the present is due largely to the continuing depression of a viscoelastic lithosphere as a result of earlier sedimentary loading.

A new way to analyse drill cuttings: a case study from Deparanie–1, Cooper Basin, South Australia

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Drill cuttings, which are released into the mud-stream during the drilling of oil and gas-bearing rock sequences, are typically examined on-site, at the surface, by a geologist using a binocular microscope. Basic petrographic features, such as lithology, staining, porosity, and hydrocarbon-content are recorded, along with cavings, recycled cuttings, mud, cement, and tramp metal. Cuttings are often the first materials to be analysed from a drill hole and therefore great importance is placed on documenting and interpreting them accurately.

In this study, we have utilised a fully-automated, quantitative, Scanning Electron Microscope-based analysis system, known as QEMSCAN, to measure archived cutting samples from the Merrimelia Formation, of Deparanie–1 in the Cooper Basin of South Australia. QEMSCAN, which has been developed by CSIRO Minerals during the past 15 years for the international mining industry, is able to recognise most rock-forming minerals, and can produce mineral maps on a cutting-by-cutting basis. Samples are presented to the machine as polished, carbon-coated, resin impregnated 30 mm diameter blocks. Parameters which can be quantified for a given population of cuttings include: modal proportions, average grain size, chemical composition, and rock type.

The present study has shown that QEMSCAN is able to resolve and quantify a high level of sedimentary textural information, including: detrital quartz grains; clay and carbonate matrix and cement phases; replacement textures; sedimentary bedding structures; diamictite textures; mineralised fracture zones; micro-fossils; detrital heavy minerals; and porosity. The system is also capable of discriminating and quantifying the distribution of kaolinite and illite within almost uniform mudstone, diamictite, and fine-grained sandstone sequences of the Merrimelia Formation.

While this technique will not replace real-time mud-logging methods, we suggest that QEMSCAN can augment existing interpretations by providing off-site petrographic

quantification of key stratigraphic sequences. This additional information is predicted to provide a new basis for basin/play analysis.

Shaly sand evaluation in low salinity reservoirs using deterministic petrophysics

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The Eromanga Basin is part of the Great Australian Artesian Basin, an active aquifer system with waters that are sometimes almost potable for humans (500 ppm NaCl). Log analysis in these fresh water sandstone reservoirs can be difficult because there is little electrical contrast between zero conductivity hydrocarbon and low conductivity fresh formation water. When clay is present there is an extra conductive path through clay-bound water that may be more conductive than that through the free water. The contrast between hydrocarbon and water bearing intervals is thus reduced further.

Newer measurements such as electromagnetic propagation or nuclear magnetic resonance are useful for identifying and quantifying hydrocarbon volumes. When these measurements are absent, older measurements must be used. Fortunately, there are ways to extract more information from them.

Conventional log analysis models assume that for water-based drilling muds hydrocarbon saturations in the filtrate invaded zone are lower than the deep ones due to flushing. Though technically correct, should the filtrate be conductive (as in the case of potassium chloride drilling mud) then the near wellbore environment is also conductive. There is then a good contrast between hydrocarbons and filtrate. Accordingly, saturations in the filtrate invaded zone (SXO) may be more reliable than those from the low contrast deep zone (SW).

Deep resistivity measurements are affected by boundary effects and again SXO may be more reliable than SW.

In general there is a relationship between SXO and SW of the form $SW = SXO^P$ where P is often around 0.5. Calculation of a pseudo SW can indicate what SW to expect. If only residual hydrocarbons are present then the results are misleading.

Care is needed to obtain reliable clay volumes, clay electrical activities, porosity estimates, and then model reservoir electrical behaviour correctly. Petrophysical models that operate in the total porosity domain such as either Dual Water or Waxman-Smits models and their close derivatives work well. The Juhasz equation or normalised Waxman-Smits equation has been used successfully.

If cores and special core analysis data are available, then capillary pressure data from special core analysis experiments can be normalised using a J-function, or other techniques. Normalised capillary pressure data can be applied to routine core measurements to obtain a saturation profile independently from wireline measurements.

A new model for the tectonic evolution of the southeastern Bass Basin, Australia

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Seismic, wireline and palynological data have been utilised to divide the sedimentary package in the southeastern Bass Basin into three mega-sequences: the pre-rift, syn-rift and post-rift. The major erosional unconformity, seen on seismic data near the Durroon–1 well, within the Early Cenomanian has been interpreted from the overall seismic reflection geometry and internal seismic facies characteristics both above and below it, to be the rift-onset unconformity. This unconformity marks the onset of the Tasman Sea rifting phase (dated 96 Ma, *A. distocarinatus* zone). This major tectonic event may have been synchronous with the initiation of sea-floor spreading in the Southern Ocean.

The structural style in the southeastern Bass Basin (Durroon Basin) is characterised by large, domino-style, tilted basement fault blocks. Fault throws are in the order of 4–5 km and occur along rotational normal faults. This is in complete contrast to the structural style in the adjacent Bass Basin to the west and northwest. There the structural style is dominated by regional subsidence and syn-sedimentary faulting along both planar and listric faults with much lesser throw.

The structural style in the Durroon Basin has been shaped through three major extensional phases that are reflected in different fault trends. The initial response to extensional forces was the development of discrete fault segments across the basin. The present day fault pattern subsequently developed through progressive propagation and linkages of the initial fault segments. The obliquity of Tasman rifting had a profound influence on the structural development. The offshore extension of the NE-trending Arthur Lineament probably acted as a buttress to limit the tensional stresses, resulting in the Late Cretaceous history of the Bass and Durroon basins being very different. However, from the Early Tertiary, the two basins were linked.

A simple shear-pure shear model of extension has been invoked to explain the major westerly-dipping

normal faults seen in the Moore Basin west of the Lord Howe Rise and the ENE-dipping basin-bounding faults in the Durroon Basin. These two basins perhaps formed initially as conjugate pair in the southeastern Australian continent during the rift valley development prior to opening of Tasman Sea. Otway rifting had already created major weakness in the crust in the area and superimposition of later Tasman Sea rift tectonics resulted in an apparently clean, sharp split in the continental crust seen in the vicinity of the shelf and slope area of the southeast Australian margin.

Tookoonooka and Talundilly: hydrocarbon plays associated with possible carbonatites

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The Tookoonooka and Talundilly structures are large, circular areas of disrupted sedimentary rocks in the Eromanga Basin. The Tookoonooka structure was initially interpreted as a volcanic centre because of possible vitric tuff, a central uplift with surrounding depression, periodic uplift, volcanic apatites, and a strongly positive magnetic anomaly.

Subsequent interpretations for both structures favoured a meteorite impact origin. Shocked quartz, typical of shock metamorphism, is described from Tookoonooka. Features compatible with impact are the circular plan with central uplift and rim structures, the 'sombrero' profile and brecciated crater-fill with low seismic velocities. The geophysical data for Tookoonooka are equivocal (high magnetics, negative gravity), whereas Talundilly (high magnetics, positive gravity) has a geophysical signature opposite to that for large impact structures (low magnetics, negative gravity).

Recent detailed airborne data have confirmed the strong positive magnetic anomaly at Talundilly. The magnetic features at Tookoonooka and Talundilly are best interpreted as pipe-like bodies similar in dimension and magnetic character to the Mount Weld carbonatite in Western Australia. The magnetic bodies are below the basement/basin interface. The presence of shocked quartz is difficult to explain, but the common assertion that shocked quartz can be only formed by impact is being questioned. The meteorite theory cannot explain the magnetic signatures nor evidence for periodic uplift.

A carbonatite emplacement at Tookoonooka would have influenced potential reservoirs units. Initial uplift, possibly after the deposition of the Birkhead Formation, resulted in a major disruption of fluvial systems resulting in coalescence of streams and confining of channels, resulting in enhanced thickness of sandstone. Erosion into underlying units was also likely, and extensive erosion and associated infilling has been recorded at several stratigraphic levels. With the impact model, linear structures at the top of the Cadna-owie Formation were interpreted as faults. However, if an uplift occurred at Tookoonooka at the same time as the transgression associated with the deposition of the Wallumbilla Formation, the transgression may have occurred as discrete steps with the formation of linear beach ridges at successive positions of the shoreline; such features would have excellent reservoir character.

The carbonatite hypothesis also provides an explanation for carbon dioxide in Cooper Basin gas. Published isotopic data indicating an igneous source are compatible with derivation from carbonatites.

VRF™ for really reliable reflectance data: recent examples of this revolutionary new technique

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Vitrinite reflectance was first used to characterise coals, because the industrial behaviour of coking coal is closely related to reflectance. Although reflectance measurement on dispersed organic matter (DOM) was a secondary development, it rapidly became popular as an indicator of thermal history, particularly for petroleum source rocks. The petroleum industry continues to employ vitrinite reflectance, but the last 10 years has brought increasing awareness that the technique has limitations. These include reliable differentiation of vitrinite from other macerals, distinction of in-situ material from lower maturity cavings, suppression of reflectance in hydrogen-rich vitrinites, and the occurrence of anomalously high maturity vitrinite reworked from older rocks. In each case, reflectance can be accurately measured but the data cannot be reliably interpreted without additional compositional information.

VRF™ uses quantitative fluorescence and reflectance of both vitrinite and inertinite to create a bivariate chart which differentiates materials of different composition and maturity. VRF™ analysis of reference coals allows these charts to be calibrated in terms of maturity and maceral distribution. Analysis of petroleum well samples from the North West Shelf, Papua New Guinea and New Zealand has revealed that existing reflectance data for DOM in marine rocks are in many cases grossly inaccurate. VRF™ has also been applied to problematic coals, when

geological and industrial objectives demand reflectances which are unaffected by suppression, or operator bias in maceral identification. VRF™ is now effective over Ro (normal vitrinite) 0.30–2.50%.

VRF™ results are presented for Kalyptea–1, which has previously been assessed using vitrinite reflectance, FAMM, and geochemical maturity indicators. Most samples are cuttings, with some core near target depth. VRF™ identifies and resolves serious problems with cavings and perhydrous vitrinite in key samples, and indicates substantially higher burial temperatures than have previously been estimated. VRF™ snapshots are also provided for a wide range of other samples, illustrating how this technique identifies contamination, and sorts out the sheep from the goats when calculating an average vitrinite reflectance value.

New exploration opportunities in the Outer Browse Basin region

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The Browse Basin offshore northwest Australia has been explored for many years. Several commercial discoveries of oil, gas and condensate have been made, with the recent oil finds at Cornea and Gwydion finally dispelling concerns that the region was predominantly gas prone.

Following an earlier well tie study in the region, Veritas DGC Asia Pacific recorded and processed a 23,592 km regional speculative 2D seismic survey in 1998–99. This survey provides a close (5 km spacing in places) grid of seismic around the Lynher, Trochus and Barcoo wells in the southwest, and continues some 550 km to the northwest around the North Hibernia, Rainbow, Polkobin and Sahul Shoals wells. The survey covers much of the outer deeper water Browse, Ashmore and Cartier regions

Regional geological evaluation of the data set has started in the southwest Browse Basin region which is currently gazetted and available for new applications in the present licence round. The evaluation area covers the Barcoo, Scott and Seringapatum sub-basins together with elements of the Leveque Shelf, Scott Plateau and Brecknock to Buffon fault zone.

It has indicated a wide variety of potential play types including stratigraphic plays in the Cretaceous, Jurassic and overlying Tertiary section, other Cretaceous to Palaeocene pinch-outs, fault block plays in the Jurassic, Triassic and deeper Palaeozoic section, Cretaceous and Jurassic drape plays unconformity plays, and wrench compression-related anticlinal plays.

Many of the leads identified appear to be combined structural-stratigraphic features, highlighting the need for 3D data coverage, regional sequence stratigraphy and careful interpretation at prospect level. A variety of DHI anomalies are present in the data set including bright and flat spots, frequency shadows, polarity reversals and gas chimneys.

Multistage deformation of linked fault systems in extensional regions: an example from the northern Perth Basin, Western Australia

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Linked fault systems identified in the northern portion of the onshore Perth Basin comprise northerly striking normal faults, the dominant structures in the basin, and hard linkages—easterly striking transfer faults. The former are either divided into segments of distinctive character by, or terminate at, the transfer faults. The fault systems were initiated by WSW–ENE extension in the Early Permian, but were reactivated by subsequent rifting with approximately W–E extension in the Jurassic. They were also reactivated by the oblique extension of NW–SE orientation associated with Gondwana continental breakup in the Late Jurassic-earliest Cretaceous. In addition to reactivation, older structures of the linked fault families controlled the development of younger fractures and folds. During the oblique extension, the linked fault systems define releasing bends, characterised by rollover anticline in the hanging wall of the Mountain Bridge Fault, and restraining bends where contractional folds are sites of major commercial hydrocarbon fields in the basin.

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Tectonic and basin elements of the Lord Howe Rise: a regional interpretation

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The Lord Howe Rise (LHR) extends for more than 1,600 km from the Challenger Plateau, west of New Zealand, to southwest of New Caledonia, in water depths from 1,000–5,000 m. The LHR is 400–500 km wide and is underlain by continental crust which detached from eastern Australia during the margin breakup that led to the formation of the oceanic Tasman Basin from 85–52 Ma.

The LHR comprises four sub-parallel provinces that extend for most of its length. From east to west, these provinces comprise:

Shallow, planated ?Palaeozoic basement of the Lord Howe Platform, overlain by thin Cainozoic oozes. To the east, the basement of the New Caledonia Basin is about 4 km deeper than the platform and of uncertain crustal affinity.

A central rifted province characterised by poorly defined basement blocks, with 2–4 km of Upper Cretaceous and Cainozoic syn- and post-rift section. This province includes the Moore Basin in the south and the Faust Basin in the north.

A western rift province in which basement and water depths are deeper than in the central rift, and the syn- and post-rift sediments are thicker. This province includes the Monawai Basin in the south and the Capel Basin in the north. In the central portion of the rise, the central and western rifts merge and the rift is known as the Gower Basin.

A western bounding ridge complex of continental origin. This province comprises the Dampier Ridge in the north and the Monawai Ridge in the south.

Regional-scale crustal lineaments, aligned along northeast–southwest and northwest–southeast trends, appear to be important in the evolution of the crust between the eastern Australian continental margin and the Tonga-Kermadec Trench. The northeast–southwest lineaments have been particularly important in segmenting the present-day structure of the LHR.

Recently acquired seismic data and satellite synthetic aperture radar (SAR) imagery suggest that the LHR may have significant long-term hydrocarbon potential. Bottom simulating reflectors (BSRs) observed in seismic data may indicate the presence of gas hydrate. In the northeast, the general coincidence of a BSR zone with the area of the Fairway Basin may indicate a thermogenic component to the gas hydrates. In this area, there is also some evidence for low-level oil slicks and films in SAR imagery; in combination with seismic indications of fluid migration through the sedimentary section, this may indicate that hydrocarbons have been generated in some places on the LHR.